

Cretaceous and Lower Tertiary Stratigraphy in Northwestern Puerto Rico

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CONTRIBUTIONS TO STRATIGRAPHY

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CRETACEOUS AND LOWER TERTIARY STRATIGRAPHY IN NORTHWESTERN PUERTO RICO

By DAVID H. MCINTYRE, JOHN M. AARON, and OTHMAR T. TOBISCH

ABSTRACT

Clastic products of submarine volcanism constitute the bulk of the upper Cretaceous and lower Tertiary stratified rocks of northwestern Puerto Rico. The rocks are separated into two contrasting suites by a major northwest-trending wrench fault. Southwest of this fault, at least 500 m (meters) of thin-bedded sandstone and calcareous mudstone, the Yauco Mudstone, and more than 1,900 m of coarse basaltic tuff and tuff breccia, the Maricao Basalt, are exposed. Both formations are of Late Cretaceous (Campanian-Maestrichtian) age. Northeast of the major fault, an indeterminate thickness of intricately faulted oxidized basalt and andesite tuff breccia and coarse tuff of Late Cretaceous (Campanian-Maestrichtian) age, the Río Blanco Formation, is in fault contact with rocks of Eocene age. The oldest unit of the Eocene sequence, as much as 1,100 m thick, is the Concepción Formation, which contains plagioclase porphyry lavas and pyroclastic rocks and rhyodacitic vitric and pumice tuffs. The Concepción is overlain conformably by as much as 1,000 m of amygdaloidal basalt lavas and pyroclastic rocks of the Mal Paso Formation. Conformably overlying the Mal Paso Formation is the Río Culebrinas Formation, which contains as much as 3,000 m of andesitic and dacitic tuff breccias, coarse tuffs, and thin-bedded volcanic sandstone and mudstone. The Río Culebrinas has a distinctive thin-bedded siliceous and calcareous mudstone, the Guacio Member, at its base. Middle Eocene Foraminifera have been collected from the Mal Paso and Río Culebrinas Formations.

The unconformity between Upper Cretaceous and Eocene rocks recognized in west-central Puerto Rico may also be present in northwestern Puerto Rico.

INTRODUCTION

The geology of northwestern Puerto Rico is being studied as part of a program of geologic mapping and mineral resource investigation of Puerto Rico conducted by the U.S. Geological Survey in cooperation with the Economic Development Administration, Commonwealth of Puerto Rico.

Upper Cretaceous and lower Tertiary stratified volcanic rocks of the San Sebastián, Central la Plata, and Rincón quadrangles of north-western Puerto Rico (figs. 1 and 2) are chiefly the products of submarine volcanic eruptions. They include both volcanoclastic rocks and lavas, although volcanoclastic rocks are far more abundant. These rocks range in composition from basalt to rhyodacite and they range in age from Campanian-Maestrichtian to middle Eocene.

The formations exposed in the report area are separated into two contrasting suites by a major northwest-trending sinistral wrench fault (fig. 3), the Cerro Goden fault. The Yauco Mudstone and Maricao Basalt (Campanian-Maestrichtian) are southwest and south of the fault. Northeast and north of the fault are the Río Blanco Formation (Campanian-Maestrichtian), Concepción Formation (Eocene), Mal Paso Formation (middle Eocene), Río Culebrinas Formation (middle Eocene), and the Milagros Formation (middle Eocene).

Special acknowledgement is due E. A. Pessagno, Jr., K. N. Sachs, Jr., and N. F. Sohl for their fossil identifications and biostratigraphic interpretations.

In this report, locations of specific points are referred to the Puerto Rico Meter Grid System coordinates in this fashion: (82,640 E.; 62,790 N.). Grid system reference marks can be found on the margins of all quadrangle maps of the island. The coordinate numbers that appear on the west and east margins of the 1958 edition of the San Sebastián 7½-minute quadrangle are in error. Coordinates of points in the San Sebastián quadrangle therefore have been adjusted to conform to the correct values shown on adjacent quadrangles.

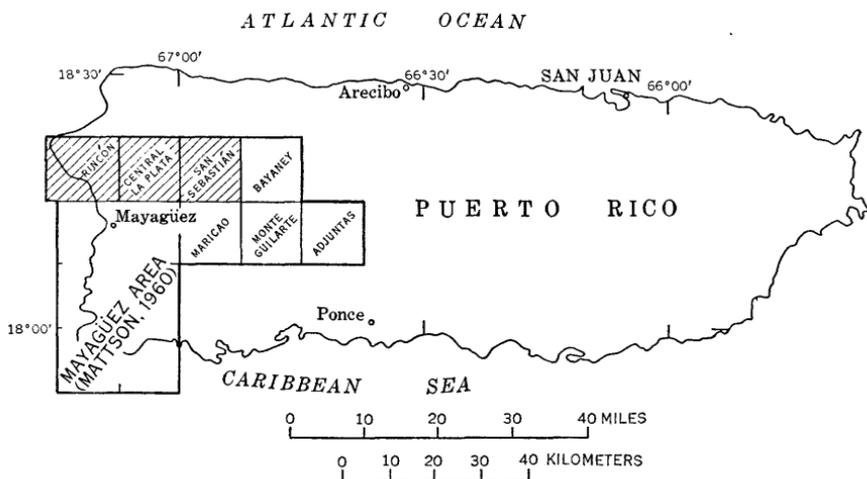


FIGURE 1.—Location of the report area (shaded).

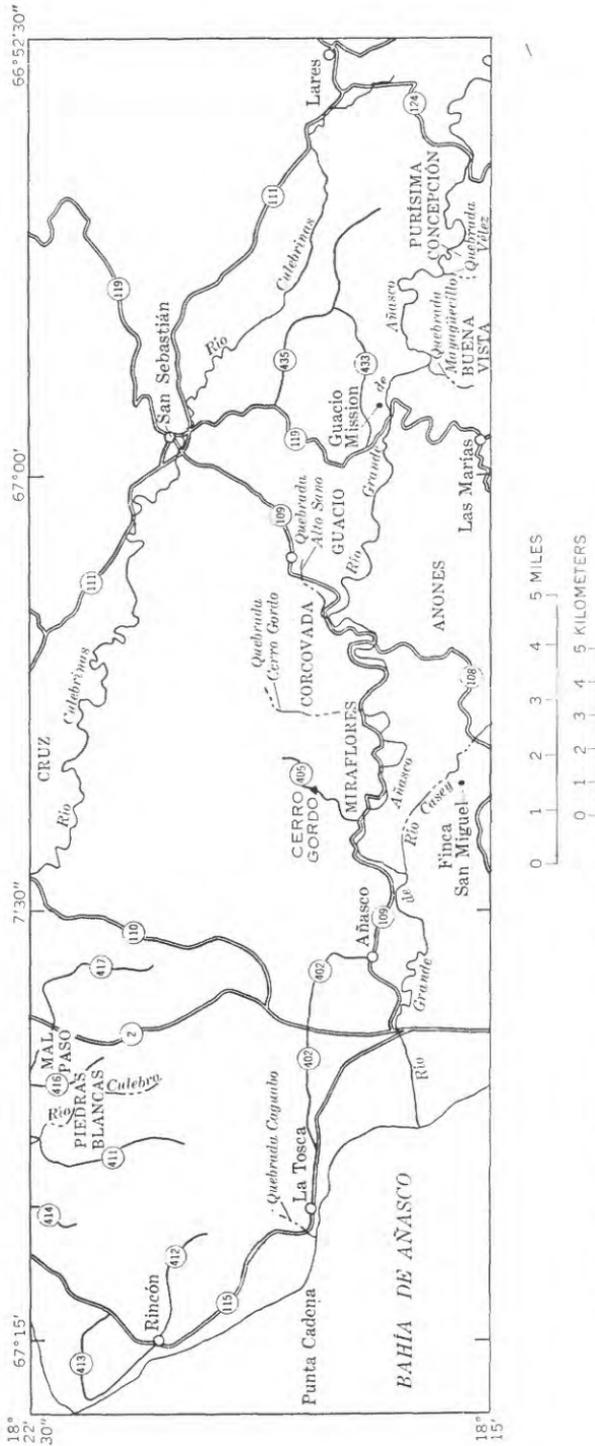
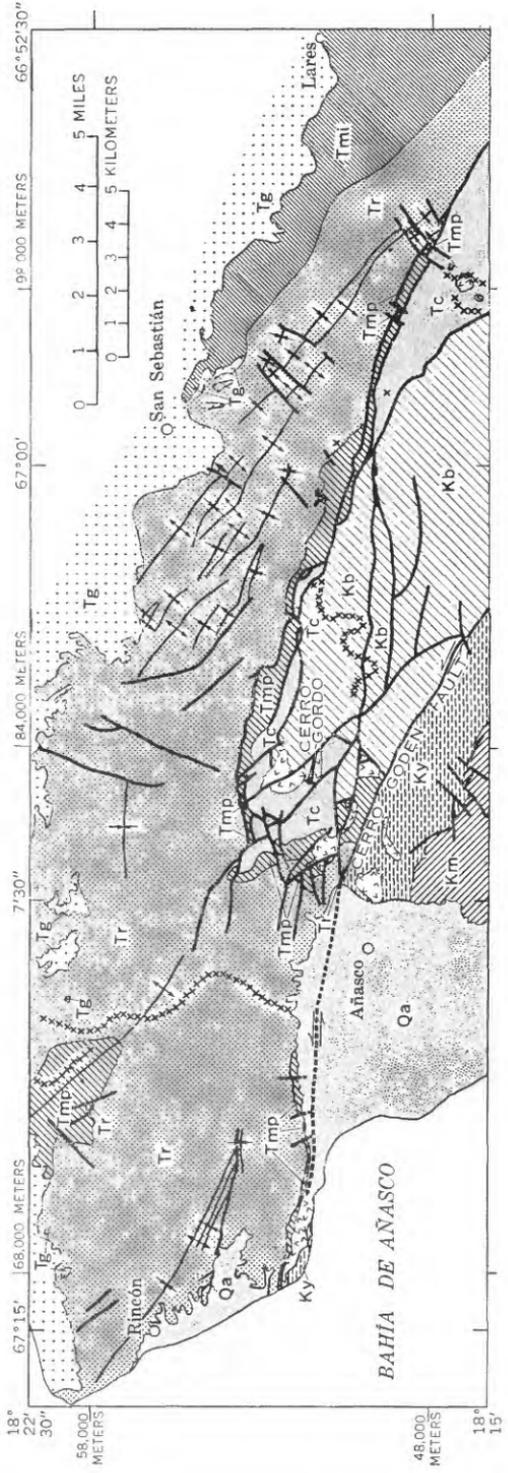


FIGURE 2.—Map of northwestern Puerto Rico showing geographic and physiographic features cited in text.



Rock classifications used in this report are based on thin-section study and chemical analyses as well as field study; they generally follow Wentworth and Williams (1932) and Williams, Turner, and Gilbert (1954), with reference to the average analyses of Nockolds (1954).

CRETACEOUS SYSTEM

YAUCO MUDSTONE

The Yauco Mudstone (Mattson, 1960, 1967) in the Central la Plata and Rincón quadrangles consists chiefly of dark-gray pyritic thin-bedded calcareous mudstone and calcilutite containing Radiolaria and abundant planktonic Foraminifera, but it also has some thin-bedded chert and thick- to thin-bedded volcanic sandstone containing plagioclase, clinopyroxene, aphyric rock fragments, and pumice. In the area 2 km (kilometers) east of Añasco, thin- to thick-bedded coarse tuff and massive tuff breccia containing abundant altered pumice are prominent constituents of the formation. A pillow lava containing clinopyroxene phenocrysts was seen 400 m (meters) southwest of the Cerro Goden fault on Highway 108.

The Yauco Mudstone is the most widespread formation now recognized in western Puerto Rico; outcrops of this unit extend somewhat continuously at least from the southwest corner of the Adjuntas quadrangle (Mattson, 1967) to Punta Cadena in the Rincón quadrangle—a distance of 55 km.

Foraminifera from samples collected along the Río Casey north of Finca San Miguel were examined and identified by E. A. Pessagno, Jr. (written commun., 1968).

Locality MCP-325 (83,000 E.; 47,760 N.):

Foraminifera:

Globotruncana linneiana (d'Orbigny)?; preservation poor.

Abundant Radiolaria; mostly Spongodiscacea.

Age: Probably early Campanian-early Maestrichtian; *Globotruncana fornicata*—*stuartiformis* Assemblage Zone.

Locality MCP-328 (83,340 E.; 47,380 N.):

Foraminifera:

Globotruncana elevata (Brotzen)

Globigerinelloides sp.

Heterohelix sp.

Age: Late Campanian to late Maestrichtian; *Globotruncana fornicata*—*stuartiformis* Assemblage Zone, *G. elevata* Subzone; *G. contusa*—*stuartiformis* Assemblage Zone.

These ages agree with many other Campanian-Maestrichtian age determinations for the Yauco Mudstone elsewhere in Puerto Rico (Mattson, 1967).

A thickness of at least 500 m of Yauco Mudstone is present in the area, but little confidence can be placed even in this approximate figure because of small-scale folding.

MARICAO BASALT

The name Maricao Basalt of Mattson (1960) is herein adopted for a sequence of thick-bedded to massive coarse basaltic tuff and tuff breccia and thin-bedded coarse tuff exposed southeast of Añasco. Mattson named the Maricao Basalt for exposures "on the Río Maricao north of Maricao" (1960, p. 337), but he did not formally propose a type locality. Better exposures of the formation occur along Route 120 northwest of Hacienda Balare, about 400 m north of the Río Maricao (93,600 E.; 40,000 N.), and these exposures are herein designated as the type locality. The formation is at least 1,400 m thick in the Central la Plata quadrangle.

The tuff breccias generally contain angular to subangular lava blocks that have clinopyroxene and plagioclase phenocrysts, although one sample contains hornblende rather than clinopyroxene. The blocks generally are scoriaceous and have amygdule fillings of chlorite. Some samples of tuff-breccia matrix contain pumice fragments, which are now altered to chlorite.

The coarse tuff and the tuffaceous matrix of the tuff breccias contain clinopyroxene and plagioclase crystal fragments, small fragments of lava and pumice, and recrystallized fossil debris that are chiefly tests of larger Foraminifera. Finely disseminated pyrite is common. These rocks generally range from light gray to dark greenish gray, but oxidized fragments impart a dark-red color to a few samples. Incipient alteration to secondary epidote, chlorite, and prehnite was observed in some samples.

The Maricao Basalt overlies the Yauco Mudstone in the Central la Plata quadrangle. The two formations are concordant and are probably conformable. Mattson (1960) indicated that the two formations intertongue in the area immediately to the south. If this interpretation is correct, the Maricao Basalt should be approximately the same age as the Yauco Mudstone (Campanian-Maestrichtian).

RÍO BLANCO FORMATION

The name Río Blanco Formation is herein adopted for rocks of Late Cretaceous (Campanian-Maestrichtian) age that form a major part of the Río Blanco Series of Hubbard (1923). Hubbard proposed no type locality for this unit. More recently, Mattson (1960) used the name Río Blanco Formation for rocks in the northeastern part of the Mayagüez area (fig. 1), but he also did not designate a type locality.

Hubbard (1923, p. 28) noted that "The best exposures of the Río Blanco Series are found along the sugar railroad east of Añasco * * *" that is, according to his map, along the north side of the Río Añasco valley in Barrios Miraflores and Corcovada. The type area we have chosen for the Río Blanco Formation includes exposures corresponding to those "best exposures" mentioned by Hubbard. The exposures occur intermittently along Route 109, the Río Añasco, and from Quebrada Alto Sano (88,700 E.; 51,300 N.) to about 200 m west of Quebrada Cerro Gordo (85,000 E.; 50,200 N.).

Outcrops of the Río Blanco Formation are in an area of deep tropical weathering; thus, no extensive outcrops of fresh rock were found even in deep roadcuts or along major streams. Most exposures consist of reddish-orange, red, reddish-purple, or purple saprolite in which only the gross textural characteristics of the parent rock generally can be discerned.

The Río Blanco Formation consists chiefly of massive tuff breccia containing angular to well-rounded blocks of basalt and pyroxene or hornblende andesite. Amygdaloidal blocks are present, but they seldom can be recognized as such in saprolite exposures. Iron-bearing minerals in the tuffaceous matrix generally are oxidized, giving fresh samples of the rock their characteristic dark-red or reddish-purple color. The blocks generally are not oxidized.

Coarse tuff, either massive or thin bedded, contains basalt and pyroxene andesite rock fragments and crystal fragments of plagioclase and clinopyroxene or hornblende.

One lava flow was seen in this unit in a roadcut on Highway 109 southwest of Quebrada la Balza.

Over much of its known outcrop area, particularly along the Río Añasco, the formation has been cut by many faults of unknown displacement, intruded by many dikes of granodioritic composition, and partly metamorphosed to the albite-epidote hornfels facies. However, in some areas—Barrio Miraflores in the Municipio de Añasco and a small area in Barrio Anones, Municipio de Las Marías—the metamorphism has only reached zeolite grade.

Three limestone exposures were found in the Río Blanco Formation, all in the Maricao quadrangle south of the report area (fig. 1). Fossils collected from these localities provide the only direct evidence concerning the age of the formation.

USGS locality 27009 (93,900 E.; 43,900 N.): Quarry immediately west of Route 120 on Sierra de Naranjal about 3 km south of Las Marías, Barrio Maravilla Sur, Municipio de Las Marías. Fossils identified by N. F. Sohl (written commun., 1959).

Pelecypoda :

Durania sp.*Durania nicholasi* (Whitfield)

Radiolitids

Indeterminate fusiform gastropod

Foraminifera abundant

Age : Campanian-Maestrichtian.

USGS locality 27010 (92,520 E. ; 43,350 N.) : Cut on Route 120, 0.8 km south of

USGS locality 27009. Fossils identified by N. F. Sohl (written commun., 1959)

Pelecypoda :

Radiolitid indeterminate

Antillocaprina sp.*Durania* sp.

Age : Campanian-Maestrichtian.

USGS locality f-35157 (94,630 E. ; 46,120 N.) : Quebrada Mayagüecillo, Barrio

Buena Vista, Municipio de Las Marías. Fossils identified by K. N. Sachs, Jr. (written commun., 1967).

Foraminifera :

Pseudorbitoides sp. cf. *P. israelskyi* Vaughan and Cole

Age : Campanian Maestrichtian.

Mattson (1960, p. 345) reported that Foraminifera identified as *Sulcoperculina* sp. aff. *S. vermunti* and aff. *S. dickersoni* were collected by T. R. Slodowski from "the quarry south of Las Marías on Route 120." All these fossils indicate a Campanian-Maestrichtian age for the Río Blanco Formation.

According to N. F. Sohl (written commun., 1968), age ranges for the rudists suggest that the limestones in the Río Blanco should be restricted to the late Campanian or early Maestrichtian.

The Río Blanco Formation is separated from the Yauco Mudstone and Maricao Basalt by the Cerro Goden fault. The contact between the Río Blanco and younger, lower Tertiary formations to the north also is faulted (fig. 3). Attitudes of well-bedded rocks in the Río Blanco indicate that the formation has been complexly deformed, probably for the most part by movement along the many faults that cut it.

Because no marker horizons were noted that could be used in measuring the amount of deformation within the unit, and because the bedding, rarely seen, varies erratically in attitude, no meaningful estimate of the stratigraphic thickness can be made at present. The estimates previously made by Mattson and by Turner (Mattson, 1960, p. 344) have no validity because they were based on the incorrect assumption that the formation was part of a simple southwest-dipping homocline.

TERTIARY SYSTEM
CONCEPCIÓN FORMATION

Near-vent dacitic and rhyodacitic pyroclastic rocks and lavas associated with two separate, but related vent areas in northwestern Puerto Rico are herein named the Concepción Formation for exposures in Barrio Purísima Concepción.

Typical exposures of the Concepción Formation are found along the Río Añasco near the Route 119 bridge (94,620 E.; 49,270 N.), along the road that follows the boundary between Barrios Purísima Concepción and Buena Vista (97,380 E.; 47,420 N. to 98,265 E.; 48,400 N.) and in Quebrada Vélez (98,170 E.; 46,200 N. to 98,460 E.; 47,570 N.). At the Río Añasco locality thin-bedded tuff is well exposed. That part of the formation dominated by lavas is exposed along the Purísima Concepción road. The intimate relation of lava and the intrusive rocks of the vent area can be seen in Quebrada Vélez. The maximum thickness of the formation in this area is about 1,100 m.

The Concepción Formation exposed in Barrios Purísima Concepción and Buena Vista, Municipio de Las Marías, contains both volcanoclastic rocks and lavas. The western part of the formation in this area is chiefly gray to green thin-bedded tuff containing altered plagioclase, pyroxene, or hornblende crystal fragments, fragments of plagioclase porphyry, and some pumice. Toward the east, however, lavas and closely related small intrusive bodies predominate. Two types of lavas are present: pale-gray to greenish-gray lava that contains abundant plagioclase, commonly as phenocrysts, and dark-green to gray lava that contains abundant clinopyroxene phenocrysts. Tuff breccias occur with the lavas. All these rocks have been somewhat altered, and many samples now contain secondary epidote, chlorite, prehnite, or zeolites. Pyrite is a common accessory mineral in many samples.

Other exposures of the Concepción Formation are related to another vent area about 14 km west-northwest of the area discussed above. Rocks immediately surrounding this second vent, the position of which is marked by the intrusive body north of Cerro Gordo, consist chiefly of greenish-gray rhyodacitic pumice lapilli tuff and coarse crystal-vitric-pumice tuff. The formation becomes progressively finer grained away from the vent area. Toward the southwest the lapilli tuff gives way to thin-bedded crystal-vitric tuff. Exposures 4 km east of the vent area reveal thin-bedded volcanic sandstone and mudstone. An exposure of thin-bedded tuff 2 km northwest of the vent contains poorly preserved planktonic Foraminifera. The Concepción is more than 800 m thick near Cerro Gordo.

In addition to abundant pumice and altered glass shards, the Concepción Formation in this area also contains plagioclase (andesine); very small amounts of hornblende, pyroxene, quartz, pyrite, and magnetite; and a few red dense oxidized lava fragments. The lava fragments are more common near the contact with the overlying Mal Paso Formation. Glass is replaced by chlorite or by microscopic intergrowths of quartz and potash feldspar.

In the area northeast of Añasco, the contact between the Concepción Formation and the overlying Mal Paso Formation is conformable; some interbedding of lithologic types characteristic of the two formations was observed near the contact. The contact is drawn at the base of the first amygdaloidal lava or dominantly purple pyroclastic rock typical of the Mal Paso Formation. Toward the east, however, the contact is a fault.

The Mal Paso Formation is middle Eocene in age; therefore, the conformably underlying, rather thin, rapidly deposited Concepción Formation surely is no older than Eocene.

MAL PASO FORMATION

The Mal Paso Formation, herein named for Barrio Mal Paso in the Rincón quadrangle, is a widespread and readily recognizable unit in northwestern Puerto Rico. The type area for the Mal Paso Formation is in Barrios Mal Paso and Piedras Blancas, Municipio de Aguada, in the northeast part of the Rincón quadrangle. Typical exposures can be seen along Route 416 for 2.7 km from the northern border of the Rincón quadrangle. In addition, excellent exposures are found along several secondary roads in Barrio Piedras Blancas, especially the one that joins Route 416 about 1.4 km south of the junction of Routes 416 and 417 (73,800 E.; 59,130 N.) and follows a ridge southwest of the Río Culebra. The formation is estimated to be at least 1,000 m thick in the type area.

The most distinctive rock type of the Mal Paso Formation is grayish-red-purple amygdaloidal basalt lava in which the amygdule fillings are white calcite and zeolites. The lavas generally are pillowed and commonly contain olivine pseudomorphs. Locally, pale-red-purple impure limestone containing planktonic Foraminifera occurs between lava pillows as lenses a few centimeters thick. Amygdaloidal basalt breccias commonly are associated with the pillowed flows. In addition, the formation contains crystal and crystal-vitric tuffs that are various shades of reddish purple, green, and gray; some contain abundant silicic glass and pumice in addition to basaltic detritus and resemble tuffs of the underlying Concepción Formation. These rocks indicate

that vents supplying silicic detritus still were active during a time dominated by basaltic volcanism.

Lava flows, or possibly intrusive rocks, of keratophyric plagioclase porphyry crop out for about 200 m along Route 119 about 1.2 km northwest of the Guacio Mission (93,500 E.; 49,630 N.). Chemical analyses of these rocks resemble one analysis of lava in the Concepción Formation exposed a few kilometers to the southeast.

The Mal Paso Formation conformably overlies the Concepción Formation and is, in turn, overlain conformably by the Río Culebrinas Formation. Direct evidence concerning the age of the Mal Paso Formation is provided by Foraminifera in calcareous tuff that outcrops at La Tosca, Barrio Caguabo, Municipio de Añasco; these were identified by E. A. Pessagno, Jr. (written commun., 1968).

Sample 255-A-54 (70,350 E.; 51,840 N.):

Foraminifera:

Globorotalia s.s. sp. (keeled)

G. aragonensis Nuttall

G. densa (Cushman)

Globigerina sp.

Age: lower middle Eocene

RÍO CULEBRINAS FORMATION

During his pioneer study in northwestern Puerto Rico, Hubbard (1923) used the name Río Culebrinas Series for rocks that crop out in the valley of the Río Culebrinas. This name has been in common use to the present day (Turner, 1958; Mattson, 1960, 1967), although no type locality has been formally proposed. The name is very useful and is herein adopted and redefined. As redefined, virtually all rocks included in the Río Culebrinas Series of previous reports are included in the Río Culebrinas Formation.

The Río Culebrinas Formation contains four principal lithic types. The base of the formation is marked by a remarkably persistent thin-bedded siliceous and calcareous mudstone and impure limestone, herein designated the Guacio Member. The Guacio Member is overlain by very thick bedded tuff breccia, very thick to thick-bedded coarse crystal-lithic tuff, and thin-bedded volcanic sandstone and mudstone that form the bulk of the formation. The relative proportions of these three rock types vary greatly from place to place.

The superb exposures of the Río Culebrinas Formation for 8.6 km along Route 2 in the Rincón quadrangle, from the intersection with Route 417 (75,700 E.; 59,600 N.) to the intersection with Route 402 (75,900 E.; 52,100 N.), are designated the type area for the formation. All lithologies, except that of the Guacio Member, are present in these exposures. Thin-bedded rocks predominate, forming approximately

60 percent of the rocks exposed. Coarse tuff forms about 35 percent of the exposures, and tuff breccia, about 5 percent.

The type locality for the Guacio Member of the Río Culebrinas Formation is in Barrio Guacio, Municipio de San Sebastián, and consists of the exposures along Route 433, immediately east of its junction with Route 119 (93,200 E.; 50,600 N.). Partly weathered thin-bedded mudstone typical of most outcrops of the member is exposed in roadcuts along the northwest-trending ridgecrest. In addition, fresh rock can be collected in the borrow pit beside the road on the inside of the bend at the northwest end of the ridge. The member is about 100 m thick at the type locality. Use of the name Guacio for this unit conforms to earlier informal usage by M. D. Turner (unpub. data). Fresh outcrops of the Guacio Member located closer to the type locality of the Río Culebrinas Formation are those in Quebrada Caguabo, 5 km southwest of the Route 2 exposures.

The tuff breccias of the Río Culebrinas Formation are very thick bedded and poorly sorted; they contain both subangular and rounded blocks ranging from 3 cm (centimeters) to more than 1 m in diameter in a matrix of poorly sorted coarse crystal-lithic tuff. The blocks are chiefly andesite or dacitic andesite that contain phenocrysts of plagioclase and hornblende. However, some contain clinopyroxene phenocrysts and others contain rare quartz phenocrysts. Algal fragments and larger Foraminifera locally are conspicuous constituents of the tuffaceous matrix. Blocks of coarse tuff and limestone are also present locally.

The very thick to thick-bedded coarse tuff contains volcanic rock fragments that have plagioclase and hornblende, or plagioclase and clinopyroxene, phenocrysts. Altered green pumice fragments are common, as are single crystals of plagioclase, clinopyroxene, hornblende, quartz, magnetite, and diagenetic pyrite. Algal fragments and broken tests of larger Foraminifera locally are abundant.

The thin-bedded volcanic sandstone and mudstone contains the same clastic constituents as the coarse tuff. In addition, planktonic Foraminifera are conspicuous in some samples.

These three lithologic types commonly grade into one another and are interbedded at all scales. Crude large-scale grading in size of blocks is apparent in many outcrops of the tuff breccia. Graded bedding is exceedingly common in the thin-bedded volcanic sandstone and mudstone.

The thin-bedded siliceous and calcareous mudstone that is the dominant lithology in the Guacio Member contains variable amounts of silt-sized volcanic debris and organic detritus, chiefly tests of planktonic Foraminifera and Radiolaria. With decreasing proportion of volcanic debris, this lithology grades into siliceous limestone. Most

outcrops of the member are deeply weathered and consist of brittle, blocky, chertlike material interbedded with clay.

The Río Culebrinas Formation conformably overlies the Mal Paso Formation, though previous workers (Hubbard, 1923; Turner, 1958 and unpub. data; Mitchell, 1954) believed that the Río Culebrinas was overlain by the rocks we now are including in the Mal Paso and Río Blanco Formations. Turner (oral commun., 1967; unpub. data) believed the Guacio to be the youngest unit of the Río Culebrinas Formation. However, our detailed mapping in the Central la Plata quadrangle has shown that the section near the Río Culebrinas-Mal Paso contact southwest of San Sebastián is overturned. Many examples of overturned graded bedding were seen in that area and areas to the southeast in the San Sebastián quadrangle. Mapping farther west in the Central la Plata and Rincón quadrangles and paleontologic data provide ample corroboration for this interpretation.

The Río Culebrinas Formation is overlain with angular unconformity by rocks of the middle Tertiary Río Guatemala Group. The middle Oligocene San Sebastián Formation (Zapp and others, 1948) overlies the Río Culebrinas in most of the area. North of Rincón, however, the Río Culebrinas is overlain by the Cibao Formation (Monroe, 1968). The Río Culebrinas Formation is about 3,000 m thick in the Rincón quadrangle and is about 2,800 m thick in the western part of the Central la Plata quadrangle. Only about 1,700 m are preserved in the area southwest of San Sebastián.

Many outcrops of the Río Culebrinas Formation contain well-preserved tests of larger Foraminifera. Most determinations indicate a middle Eocene age for the formation, although some of the taxa do range into the late Eocene. The following is a list of fossils from an outcrop in the lower part of the formation in Barrio Cruz, Municipio de Moca, near the northwest corner of the Central la Plata quadrangle (K. N. Sachs, Jr., written commun., 1967).

USGS locality f-35158 (81,420 E. ; 59,530 N.) :

Foraminifera :

- Nummulites wilcoxi* (Heilprin), abundant
- Amphistegina* sp., common
- Discocyclina* (*Discocyclina*) *marginata* (Cushman), abundant
- Asterocyclina habanensis* Cole and Bermudez, abundant
- Lepidocyclina* (*Polylepidina*) *antillea* Cushman, rare
- Sphaerogypsina* sp., rare
- Eorupertia* sp. cf. *E. bermudezi* Ansigard, rare

Algal fragments, abundant

Sachs regards this as a typical middle Eocene fauna, closely resembling that described by Cole and Gravell (1952) from Peñon Seep, Cuba.

DISCUSSION

Many uncertainties remain concerning correlation of formations discussed in this report with those exposed elsewhere in Puerto Rico. The problems involving the early Tertiary formations are particularly acute; at present no detailed correlations between northwestern and west-central Puerto Rico are possible, chiefly because the intervening area has not been studied in detail. Mattson (1967), however, has suggested some correlations, based upon his detailed work in west-central Puerto Rico and reconnaissance to the northwest. According to Mattson (1967, p. B23), the rocks we here define as the Mal Paso Formation may correlate with the Anón Formation of west-central Puerto Rico. Available paleontologic evidence shows that the ages of the two formations are indeed similar. However, the lithologic characters of the two formations contrast sharply; the Mal Paso is dominated by basalt lavas and pyroclastic rocks, whereas the Anón Formation is chiefly dacite, according to the Rittman definition (Mattson, 1967, p. B30).

At another point in his discussion Mattson (1967, p. B31) correlated the Río Culebrinas with the Anón Formation. These two units may well be genetically related. However, the Anón contains much lava, whereas no lava has been recognized in the Río Culebrinas. The Anón may prove to be material deposited close to one of the vents that supplied detritus for the Río Culebrinas. Detailed work in the Monte Guilarte quadrangle will be necessary before this relation can be considered more than a possibility.

Closer at hand, a correlation problem exists between the Río Culebrinas Formation and the Milagros Formation (Nelson and Tobisch, 1967) that crops out in the eastern part of the San Sebastián quadrangle (fig. 3) and in the Bayaney quadrangle. Exposures northwest of Quebrada Negrito in Barrio Espino, Municipio de Lares, show that the contact between rocks of the Río Culebrinas Formation and those of the underlying Milagros are conformable and gradational. Moreover, the lithologies of the two formations are similar. The Guacio Member of the Río Culebrinas, always present at the base of the Río Culebrinas in the area to the southwest, is not present where the Río Culebrinas rests on the Milagros. This contact may not be equivalent to the basal contact of the Río Culebrinas that is recognized in the area to the southwest, and the Milagros may be in part equivalent to the lower part of the Río Culebrinas of the southern area.

Foraminifera recently collected from the Matilde Formation, which conformably underlies the Milagros, tend to support this interpre-

tation. The fossils were identified by E. A. Pessagno, Jr. (written commun., 1969).

Locality B-5 (106,540 E.; 50,800 N.):

Foraminifera:

Globorotalia lehneri Cushman and Jarvis

G. aragonensis Nuttall

Age: early middle Eocene

This determination indicates that the overlying Milagros Formation most probably is middle Eocene in age, the same age as the Río Culebrinas Formation.

A very significant result of Mattson's work in west-central Puerto Rico was the recognition of an important unconformity between Cretaceous and middle Eocene rocks in that area (Mattson, 1966, 1967). Paleocene rocks and possibly also lower Eocene rocks are missing in northwestern Puerto Rico, so the unconformity may be present in this area as well.

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